Amplifier Linearization Using Simultaneous Harmonic and Baseband Injection

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***Abstract*—A novel linearization scheme utilizing injection of distortion signal at the input of amplifier is described. Harmonic and baseband signal generated by predistortion circuits is fed to the input of the main amplifier and by controlling the power level of the harmonic and baseband signal properly, mixing products can be made to cancel out with the FET inherent distortion signals. Unlike many other techniques, no precise phase adjustment is required for the RF signal path. For verification, the two-tone performance of a constructed linearized amplifier is measured and a reduction of the third-order IMD power level of about 27 dB is observed.**

***Index Terms*—Amplifiers, linearization, intermodulation.**

I. Introduction

With the introduction of digital-modulation for enhanced spectral efficiency, the linearity of microwave amplifier has become a major issue in wireless communication systems. A variety of schemes such as feedforward, feedback, and predistortion have been reported. Recently, harmonic feedback [1], harmonic feedforward [2], and baseband feedforward [3] were also reported. These schemes differ in the degree of complexity, stability, and performance.

In this work, a new linearization scheme making use of simultaneous baseband and harmonic injection is introduced. Proper level of distortion signal at $2f_o$ and baseband are fed to the input of the main amplifier to mix with the fundamental signal. This technique has several advantages over the harmonic and baseband techniques [1]–[3], such as the elimination of precise phase shifting elements and achieving higher IMD3 suppression.

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II. Formulation

Fig. 1. shows the equivalent circuit under consideration. In the configuration, the nonlinear current sources at the FET drain and gate are respectively, i_{dsn} and i_{gsn}, where

$$i_{dsn}(t) = g_2 v_{gs}^2(t) + g_3 v_{gs}^3(t) \tag{1}$$

$$i_{gsn}(t) = \frac{d}{dt}\left[C_2 v_{gs}^2(t) + C_3 v_{gs}^3(t)\right] \tag{2}$$

and the linear part is explicitly specified in the diagram. Using Volterra series and the method of nonlinear current [4], the third order intermodulation distortion signal at the output load is

$$\begin{aligned} &v_L(\omega_1, \omega_1, -\omega_2) \\ &\quad = i_{ds3}(\omega_1, \omega_1, -\omega_2) \times H_{LD} + i_{gs3}(\omega_1, \omega_1, -\omega_2) \times H_{LG} \end{aligned} \tag{3}$$

where H_{LD} and H_{LG} are the transfer function from the i_{dsn} and i_{gsn} to the load, respectively. After some manipulation, i_{ds3} and i_{gs3} can be expressed as shown in (4) and (5) at the bottom of the page.

Assuming that

$$\omega_o \approx \omega_1 \approx \omega_2$$

$$v_{gs1}(\omega_1) \approx v_{gs1}(\omega_2) = v_{gs1}(-\omega_2) = |v_{gs1}(\omega_2)|$$

$$v_{gs2}(\omega_1, -\omega_2) = v_{gs2}(\Delta\omega) = |v_{gs2}(\Delta\omega)|$$

$$v_{gs2}(\omega_1, \omega_1) = v_{gs2}(2\omega_1) = |v_{gs2}(2\omega_1)|\, e^{j\theta}.$$

As a result, we have

$$\begin{aligned} &v_L(\omega_1, \omega_1, -\omega_2) \\ &\quad = \tfrac{4}{3}\, g_2 v_{gs1}(\omega_1) v_{gs2}(\Delta\omega) H_{LD} \\ &\qquad + \tfrac{2}{3}\, g_2 v_{gs1}(\omega_1) v_{gs2}(2\omega_1) H_{LD} + g_3 v_{gs1}^3(\omega_1) H_{LD} \\ &\qquad + j\omega_o \tfrac{4}{3}\, C_2 v_{gs1}(\omega_1) v_{gs2}(\Delta\omega) H_{LG} \\ &\qquad + j\omega_o \tfrac{2}{3}\, C_2 v_{gs1}(\omega_1) v_{gs2}(2\omega_1) H_{LG} \\ &\qquad + j\omega_o C_3 v_{gs1}^3(\omega_1) H_{LG} \\ &\quad = a v_{gs1}^3(\omega_1) + 2\beta v_{gs2}(\Delta\omega) + \beta v_{gs2}(2\omega_1) \end{aligned} \tag{6}$$

$$i_{ds3}(\omega_1, \omega_1, -\omega_2) = 2g_2 \frac{2v_{gs1}(\omega_1)v_{gs2}(\omega_1, -\omega_2) + v_{gs1}(-\omega_2)v_{gs2}(\omega_1, \omega_1)}{3} + g_3 v_{gs1}(\omega_1) v_{gs1}(\omega_1) v_{gs1}(-\omega_2) \tag{4}$$

$$\begin{aligned} i_{gs3}(\omega_1, \omega_1, -\omega_2) = j(\omega_1 + \omega_1 - \omega_2) \times \Bigg\{ 2C_2 \left[\frac{2v_{gs1}(\omega_1)v_{gs2}(\omega_1, -\omega_2) + v_{gs1}(-\omega_2)v_{gs2}(\omega_1, \omega_1)}{3}\right] \\ + C_3 v_{gs1}(\omega_1) v_{gs1}(\omega_1) v_{gs1}(-\omega_2) \Bigg\} \end{aligned} \tag{5}$$

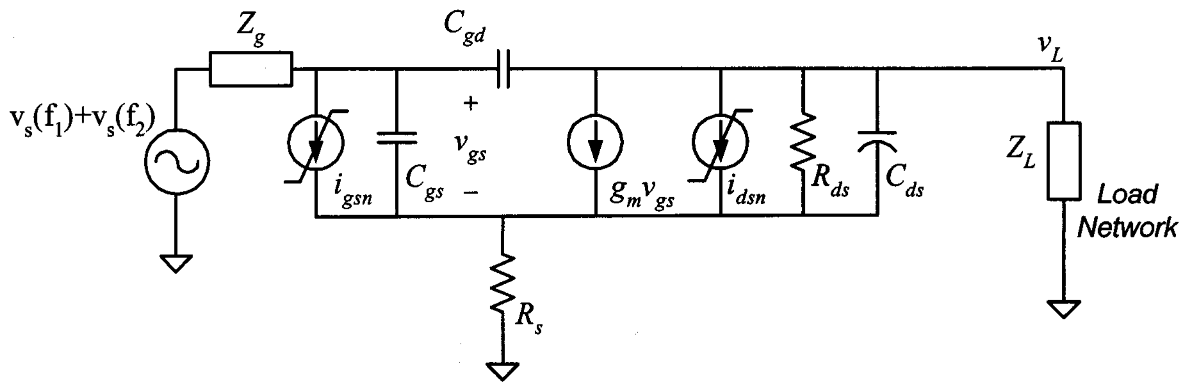

Fig. 1. Equivalent circuit for nonlinear analysis.

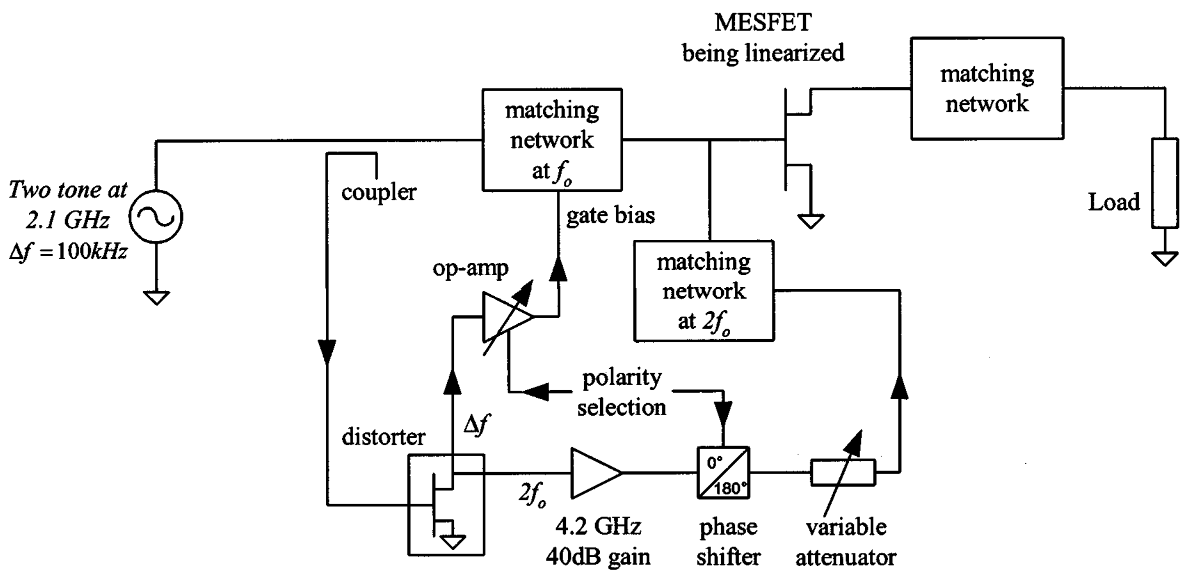

Fig. 2. System block diagram of the proposed scheme.

where

$$\alpha = g_3 H_{LD} + j\omega_o C_3 H_{LG} \tag{7}$$

$$\beta = \frac{2}{3}\, g_2 v_{gs1}(\omega_1) H_{LD} + j\omega_o \frac{2}{3}\, C_2 v_{gs1}(\omega_1) H_{LG}. \tag{8}$$

It is clear from the above expression that by adjusting the magnitudes of $v_{gs2}(\Delta\omega)$ and $v_{gs2}(2\omega_1)$ properly, the distorted signal $v_L(\omega_1, \omega_1, -\omega_2)$ may be reduced to zero and hence an improvement in IMD3 performance.

III. Experimental Results

Fig. 2 shows the configuration used for the experimental demonstration of the proposed scheme. The transistor used is Siemens CFY30 and the main amplifier is designed to operate at 2.1 GHz. A MESFET predistortion circuit is employed to utilize the strong second-order nonlinearity near pinch-off for the generation of the required $2\omega_o$ and $\Delta\omega$ frequency components. The harmonic signal at $2\omega_o$ is subsequently amplified by a multi-stage amplifier centered at 4.2 GHz. The strength of the harmonic signal is made adjustable by using a variable attenuator. The baseband counterpart is amplified by an operational amplifier with adjustable gain. In this experiment, the main amplifier is operated at 2.5 dB back-off from P_{1dB} and a two-tone signal at 2.1 GHz with 100 kHz spacing is applied. For application to wideband signal amplification, the phase response characteristics of both the RF and baseband amplifiers across the channel bandwidth must be addressed [5] such that high performance IMD reduction can be attained.

Although phase adjustment is not required in theory, in reality, polarity selection is needed to provide a positive or a negative sign for both the harmonic and baseband paths. It should be noted that a precise phase adjustment at $2\omega_o$ is not required and a phase accuracy of $\pm 60°$ is found to be sufficient. Distortion cancellation can be achieved by simply adjusting the power level of the harmonic and baseband signals.

In the proposed method, the IMD3 signal is found to be suppressed by 27 dB, upon varying the gain of the harmonic and baseband paths properly. The measured injection signal level of harmonic and baseband components are −19.4 dBm and 84 mV p-p respectively. This circuit configuration can also be used for the implementation of the conventional low-frequency injection method [3] by turning off the harmonic path. In the low-frequency only injection approach, the IMD3 component is suppressed by approximately 5.5 dB.

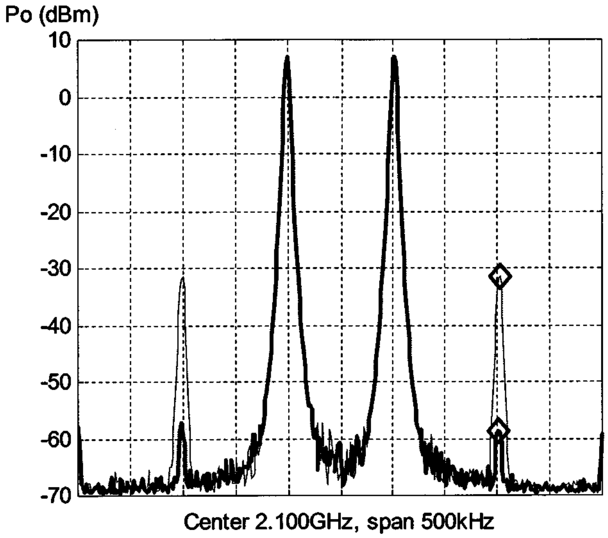

Fig. 3. Measurement results of two-tone test with and without suppression.

IV. Conclusion

A new approach for the linearization of microwave amplifiers by using both harmonic and baseband injection are described. The principle of intermodulation reduction is explained and the conditions for perfect cancellation are derived. For experimental verification, an amplifier together with the distortion cancellation circuitry is constructed. Two-tone test performed shows 27 dB reduction in IMD3 distortion and 21.5 dB improvement over the low frequency scheme.

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